TITLE: Use of an Instrumented 120MM Projectile for Obtaining In-Bore Gun Dynamics Data

USE OF AN INSTRUMENTED 120MM PROJECTILE FOR OBTAINING IN-BORE GUN DYNAMICS DATA

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Simulation work undertaken by DERA to investigate the dynamic behaviour of gun systems during firing has predominantly used the existing package of SIMBAD. In-bore behaviour of the projectile has had little experimental data to increase confidence in the modelling predictions. A programme of work was started in 1996 for the UK MoD with the aim of designing, building and firing a number of instrumented projectiles, the final objective being to obtain data with which to validate a model of the Challenger 2 MBT L30 gun system.
The UK design consists of a 16-channel data-logger, which captures the information during in-bore motion together with a specially designed battery assembly. Data is stored on board and downloaded once the projectile has been recovered. Instrumentation consists of six accelerometers and six displacement transducers for the purposes of measuring overall projectile motion as well as in-bore balloting of the projectile relative to the barrel.
Three projectiles were fired from a smoothbore 120mm L30 gun system in March 2000 and retrieved using over-water recovery. The last round was fired with a muzzle velocity of 1550m/s resulting in a peak acceleration of 42,000g. All data-loggers and accelerometers survived the launch along with a number of the displacement transducers. Although the data gathered proved insufficient for full model validation purposes, important lessons were learnt regarding instrumentation components, particularly battery design and assembly. These lessons are being incorporated into a series of instrumented firings planned for a 90mm electro-magnetic launcher.

INTRODUCTION

The Defence Evaluation and Research Agency (DERA) has conducted applied research for the UK Ministry of Defence over many years into the accuracy and consistency of conventional gun systems and projectiles. One strand of this work investigates the in-bore dynamics of the system using the gun dynamics codes such as SIMBAD [1, 2].

An initial study into technology [3] of possible use in the instrumented projectile was conducted in 1994. The overriding conclusion was that the best method for obtaining data would be by the use of onboard transducers connected to a data recorder (logger), with the latter being retrieved from a fired projectile and the data downloaded. Work in other areas of the DERA had successfully used onboard recorders, in measuring projectile fin temperatures during free flight [4]. Work prior to 1995 had centred on the use of a 155mm artillery shell

[5], since the useable volume within a 155mm shell was more than adequate for the purposes of housing the proposed instrumentation. Two schemes for mounting the data recorder in the nose and in the base of the round were formulated. The simple data recorder and accelerometer package recorded a maximum axial deceleration of 3,000g, well below the expected axial acceleration during firing of 20,000g or more but was sufficient to demonstrate a simple "proof of principle" for gun fired projectiles.

Due to subsequent budgetary limitations the 155mm work was dropped as it was felt that sufficient knowledge and experience had been gained to transfer the technology directly to a large calibre Main Battle Tank (MBT) type gun.

A clear definition of the requirements of an 'instrumented carrier projectile' for the validation of the gun dynamics shot models was required. With this in mind, input data values used in the SIMBAD dynamics codes to model the British Army's L23A1 APFSDS projectile fired from their L11 120mm gun system (Challenger 1) were revised and checked. Selected sensitivity studies were conducted aimed at obtaining predictions on the typical and peak displacements, velocities, accelerations and forces experienced by the L23A1 APFSDS projectile during its in-bore travel.

CARRIER PROJECTILE CONSIDERATIONS

Since 120mm APFSDS ammunition remains the primary nature of shot used by the British Army, it was logical to validate the modelling work using such a projectile. There is one immediate problem apparent when looking at any APFSDS projectile for use as an instrumented carrier, which is that on exit from the gun the projectile splits into several components. Use of the penetrator as a data-logger carrier would not be feasible as safe recovery is almost impossible. Both penetrator and sabot petals had insufficient internal volume to house the proposed data-loggers and battery. A 140mm round was also considered but still resulted in insufficient space [6].

The nearest workable type of projectile that could be used was the L23A1 proof shot. Though this was not specifically designed to exhibit similar dynamic behaviour to the L23A1 it had similar mass properties and identical methods of obturation so that an identical charge (L8) could be used. The obvious advantage of the proof shot is that it is not designed to break up on shot exit, allowing for full use of the internal volume and allowing the design to be kept axis-symmetric along the shot's axis of travel. An axis-symmetric design has two notable advantages. Firstly, overall centre of mass and inertia can be controlled to give close agreement with the L23A1 APFSDS projectile. Secondly, the data logger, power supply and transducers can be mounted along the axis of rotation, which if fired from a rifled barrel will reduce the amount of rotational acceleration on these components.

PROJECTILE CAPTURE

One consideration, tied closely to the choice of carrier projectile and its design, is the method by which any such projectile will be ultimately recovered. There were several possible methods:

- vertical trajectory recovery;
- over water recovery;

- over snow recovery;
- on-board projectile telemetry;
- sand butt recovery.

Although there were good and bad reasons for all of the above, Over Water Recovery (OWR) was chosen, as the DERA site at Shoeburyness had such facilities. This method involves firing over a shallow estuary at high tide so that the water provides a softer impact, waiting for the tide to go out and then recovering the projectile from the exposed ground.

MODELLING STUDIES

A comparison of the L23A1 APFSDS projectile with a possible 'instrumented carrier projectile' candidate, i.e. L23A1 proof shot was made [6]. The aim of this work was to determine to what extent changes in mass, stiffness, inertia etc. affected the dynamic response during firing. Both static and dynamic analyses, using Ideas [7], Algor [8], and SIMBAD were used for this purpose and to obtain definitive statements on the typical and 'worst case' accelerations, velocities and displacements of the L23A1 projectile for use in determining the specifications necessary for the instrumentation package. (See Figure 1 below).

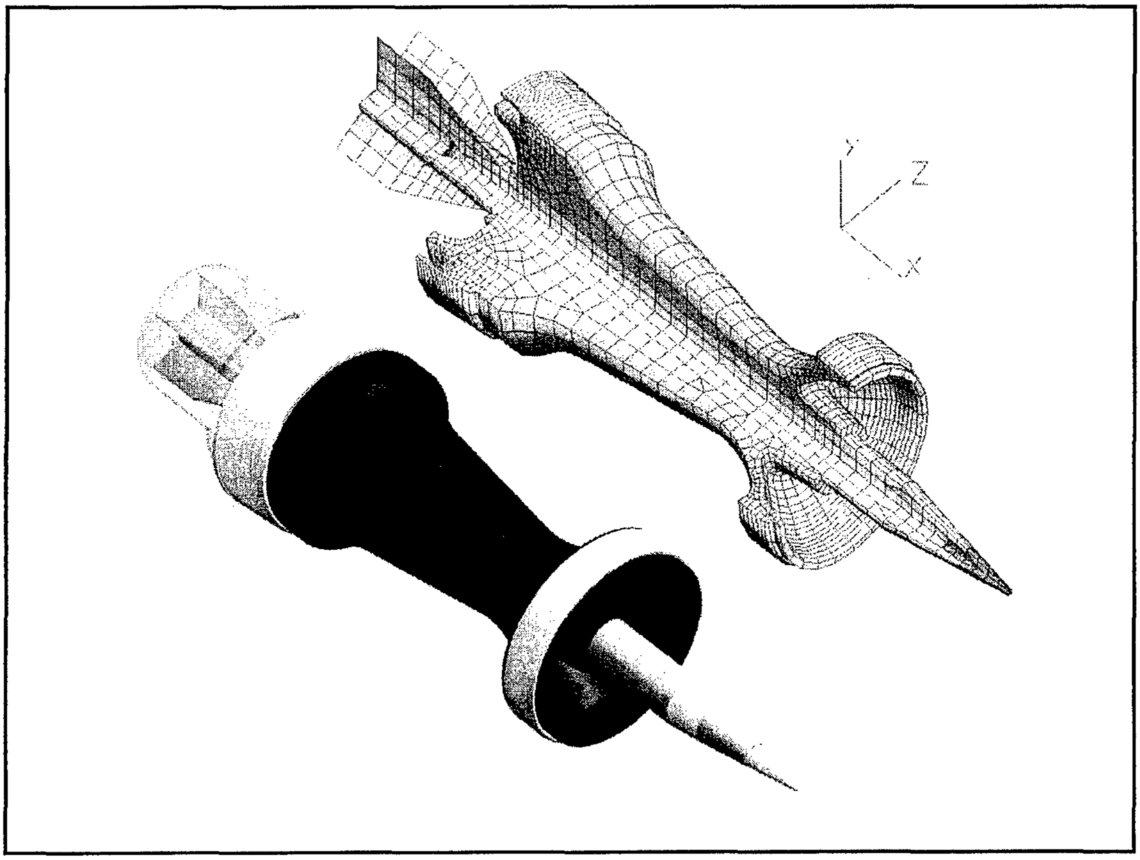

FIGURE 1. CAD & FEA models of the L23A1 APFSDS for use in the modelling studies.

The comparison of the dynamic response of the two projectiles was undertaken using SIMBAD. Numerous runs were performed to fully assess the two projectiles with the aim of finding a 'worst case' result for each projectile so that an upper limit on the specifications for the various transducers could be made.

Axial shot acceleration was seen to reach a maximum of 36,900g. Lateral accelerations of 920g and 770g were seen in the APFSDS and proof shot respectively. Instantaneous accelerations, which also include that due to pitch/yaw, gave peak accelerations of 2,040g in the APFSDS round and 1,940g proof projectile.

Runs simulating the projectiles fired from smoothbore and rifled barrels showed that the differences in projectile response between a rifled and smooth bore barrel were smaller than the differences caused by other effects. This indicated that the use of a smoothbore gun was an option for gaining data to verify shots models fired from a rifled barrel.

Bore profile or barrel straightness has been shown to be one of the most important factors that affect the gun dynamics models. It is believed to play an equally important role in real gun systems and may be the major contributor to differences in barrel MPIs. To demonstrate its effects, and to check to ensure that the maximum values of shot motion were not exceeded, experimental bore profile data for the vertical and horizontal planes were introduced into the L11 barrel model. The particular barrel bore profile used was that of one known to produce a particularly harsh response in the shot. Most importantly, instantaneous lateral acceleration on the projectile in the vertical plane increased to give values of 3,100g and 2,100g in the APFSDS and proof projectile respectively.

In summary the worst case values based on the use of experimental bore straightness data to which any instrumented projectile needed to survive and measure are given in Table 1 below. The acceleration along the barrel for these simulations is of the order of 37,000g and is by far the predominant motion. This was the maximum acceleration that the all transducers were designed to survive and operate under.

Table 1. Peak values of criteria for measurement.

Property	Maximum value
Absolute C of M bounce displacement	±8.0mm
C of M bounce wrt barrel axes	±0.8mm
Absolute C of M pitch/yaw angle	±2.5mrad
Absolute C of M pitch/yaw angular rate	±7.5rad/s
C of M pitch/yaw angle wrt barrel axes	±2.5mrad
Absolute transverse acceleration	±2,038g
Maximum frequency content of transverse accelerations	3.0 kHz to 4.0 kHz
Absolute axial velocity (shot exit)	1542m/s ±25m/s
Absolute axial acceleration	36,878g
maximum rotational acceleration (slipping band)	79,300rad/s^2
maximum rotational velocity (slipping band)	53Hz (333rad/s)
maximum centripetal acceleration (slipping band)	6653m/s^2 (678g)
Sabot/proof body transverse bending	±0.02mm
Breech pressure	434MPa
Shot exit time	10.50ms
Time to first axial & transverse motion	2.23ms
Time to 1%, 10% & 100% of maximum axial acceleration	2.63ms, 4.13ms, 6.38ms
Maximum distributed force on the driving band	±1.0MN
Maximum distributed force on the centring band	±3.0kN

INSTRUMENTATION

ACCELEROMETERS

Feasibility studies [3] indicated that accelerometers were the most appropriate transducer for in-bore measurement. One important consideration was cross-axis sensitivity. With a typical value of 5%, this would equate to a measurement error in the lateral plane almost as large as the expected accelerations. Also any slight pitch or yaw of the projectile (or a accelerometer misalignment) will introduce a component of the axial acceleration into the transverse measurement axis. If the axial acceleration is 37,000g then a pitch/yaw angle of 2.5 mrad will result in a transversely mounted accelerometer detecting a component of this acceleration equal to 92g. Although this is sufficiently small (3-5%) not to swamp the signal being measured, it is not a negligible effect, and represents a significant amount of noise.

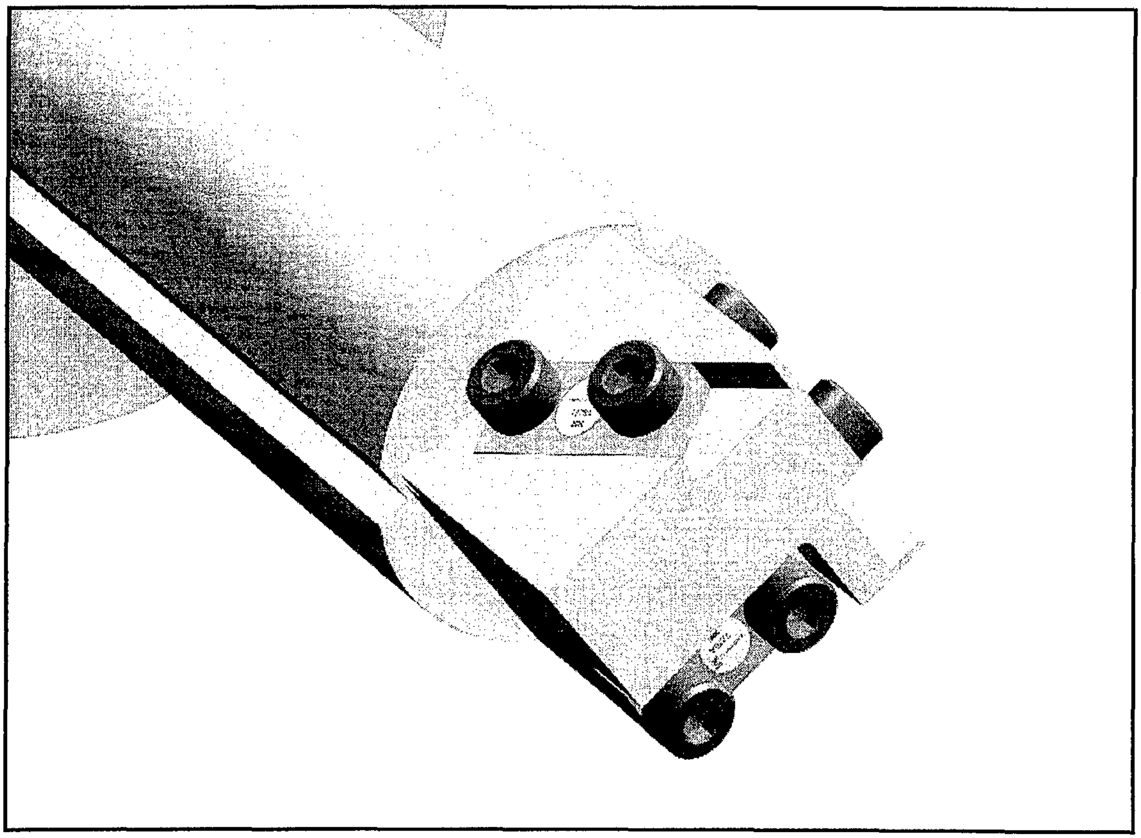

FIGURE 2. Accelerometer mounting on instrumentation carrier.

Of the possible accelerometers currently available, only the Endevco 7270A piezo-resisitive accelerometers could meet the specification [9]. The 7270A-20K (20,000g range, 60,000g limit) was the accelerometer of choice. Of the 18 accelerometers used in the final firings the mean cross-axis sensitivity was measured at 1.71% with a standard deviation of 0.41%. At worst (40,000g axial acceleration) this would give an additional 680g ±330g due to cross-axis sensitivity. This could be removed from the results though, knowing the exact cross-axis-sensitivity for each accelerometer and having measured the axial acceleration. To fully minimise the cross-axis sensitivity, the accelerometers measuring in the transverse (lateral) plane were mounted at an angle of 30 degrees to the axial acceleration. (See Figure 2).

DISPLACEMENT TRANSDUCERS

To measure projectile motion relative to the barrel, displacement transducers were chosen. No commercially available transducers were readily available. However, a capacitive type known to work up to 5,000g was sourced from a firm (Si-Plan Electronics Research Ltd.). These were modified such that they would withstand accelerations up to 50,000g [10] (See Figure 3). Using these at two locations on the projectile body would allow both displacement and rotation of the projectile to be calculated.

These could not easily be used in a rifled barrel, which made the use of a smoothbore barrel essential. Also, bore wear needed to be minimised and carefully measured, as the resolution of these devices was sensitive enough to detect bore wear of 0.01mm (10μm).

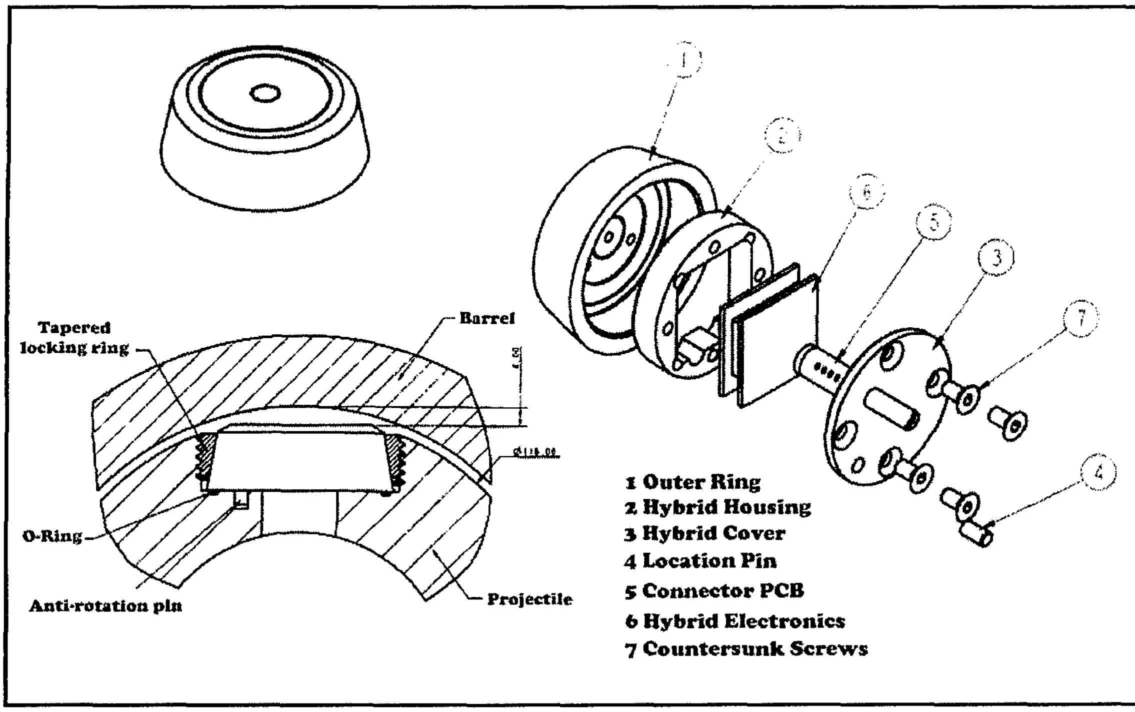

FIGURE 3. Exploded view of displacement transducer and detail of assembly into projectile.

DATALOGGER AND BATTERIES

The data recorder chosen was designed and manufactured by DERA in association with Deltatek Defence Ltd. It is a 16-channel, 12-bit, solid state device. It was designed to withstand a maximum 50,000g-shock load. Similar designs had been tested and withstood

80,000g [4]. It was hard mounted centrally in the instrumentation carrier sub-assembly by 'potting' compound introduced in a vacuum to reduce voids in the mixture.

A relatively simple battery pack was designed to supply power to the data-logger and transducers. This was constructed from standard Nickel-Cadmium (Duracell type) batteries arranged in stacks within a Nylon and aluminium bobbin and hard mounted in place in a similar fashion to the data-logger. The design was such that it formed a ring, which surrounded the main instrumentation carrier sub-assembly (See Figure 4). This ensured that the cable runs from battery to transducers were minimised.

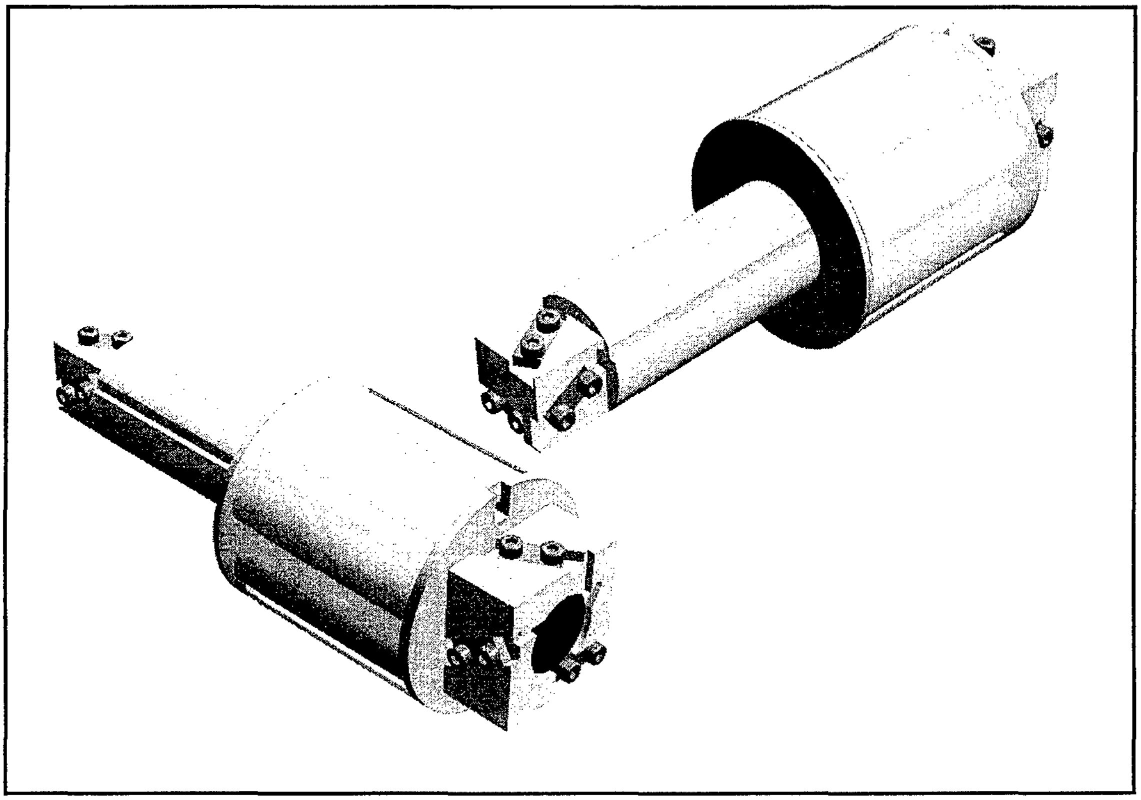

FIGURE 4. Instrumentation carrier and battery pack.

There were initial concerns about the battery life and ability of the battery to keep the logger's memory powered until recovered. Subsequent testing showed that for a standard firing, the battery would keep running for approximately 3 hours, long enough for data recovery.

The final overall design is shown in Figure 5. The package consisted of six Endevco accelerometers, six Si-Plan capacitive displacement transducers, one 16 channel DERA-Deltatek data-logger and a battery unit. All transducer cabling was encapsulated in potting compound during construction. Just prior to firing, the battery was connected to all transducers and logger through access in the front of the round. Trigger levels etc. on the data-logger were set using a laptop PC connected to the logger. The end cap was then screwed in place, using a rubber O-ring seal to prevent ingress of seawater.

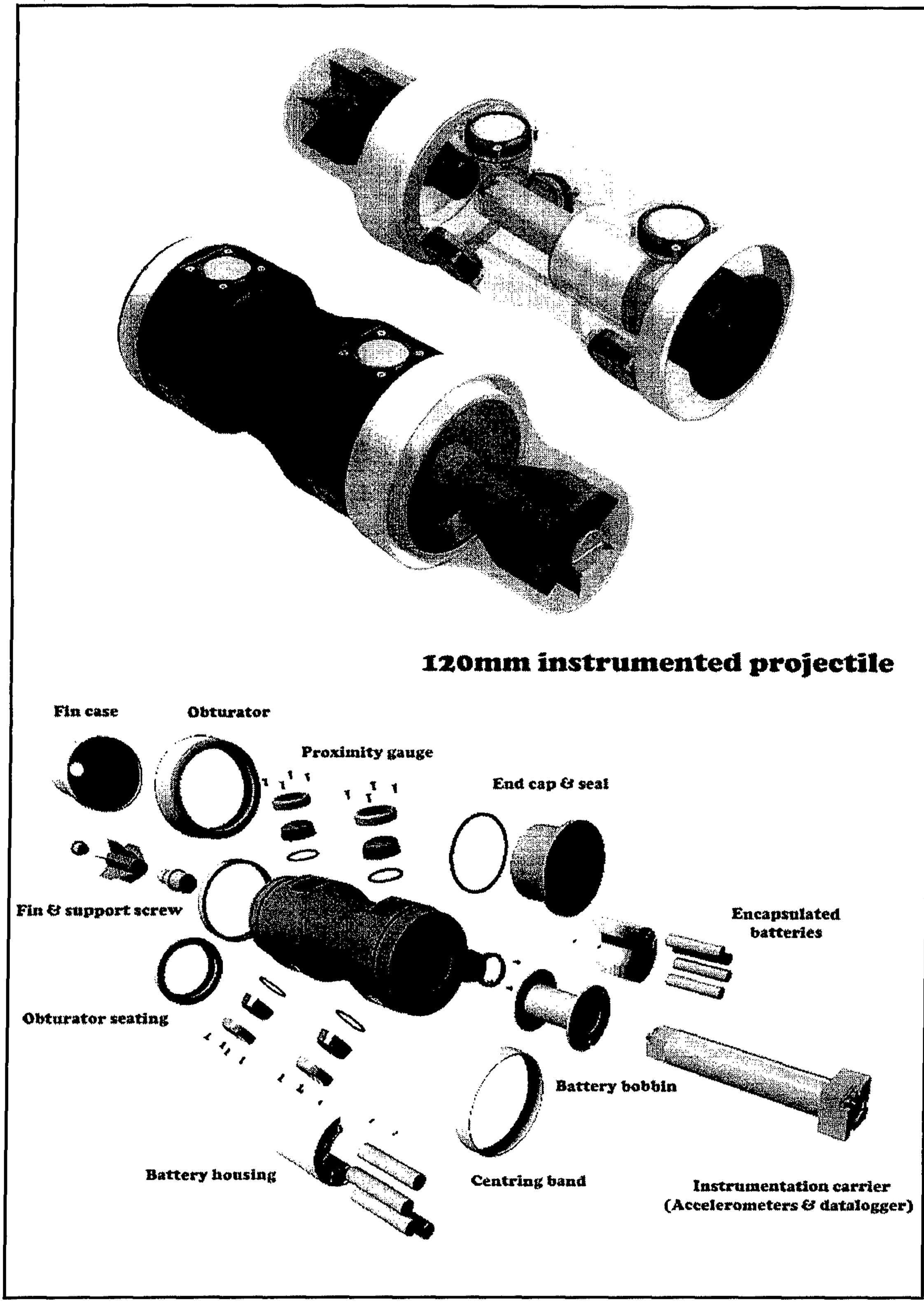

FIGURE 5. Exploded view of the 120mm instrumented projectile.

EXPERIMENTAL FIRINGS

A firing trial for the instrumented projectiles took place in March 2000 at DERA Shoeburyness, UK [11]. A smoothbore 120mm gun system fixed to a firing stand was used. In all other respects the gun system was identical to the Challenger 2 L30.

Modified L8 charges were used as the propellant. These were adjusted to give the correct muzzle velocities required for the projectiles. Three instrumented rounds were fired. All three were recovered successfully using the OWR method.

The first round was fired at a reduced muzzle velocity (24,000g). Before firing it was found that the end cap would not screw fully into the projectile body and the O-ring seal was not fully compressed. Despite this it was still fired. However, after recovery it was found that some water had penetrated into the instrumentation compartment and had 'short circuited' the batteries. A small amount of data was recovered from the data-logger before the batteries failed completely. Further checks showed that the data-logger and all accelerometers were still fully functional, though only one of the displacement transducers was found to be operational.

The second round was also fired at a reduced muzzle velocity (24,000g), due to the problems experienced with the first round. Examination of the recovered data revealed that the data-logger had triggered prior to its in-bore travel and only low level noise was present on each channel. It is not known what caused the false trigger. Further checks showed that the data-logger and accelerometers were still fully functional along with two of the displacement transducers. Testing of the battery showed this was also working correctly.

The final round was fired at a higher muzzle velocity (42,000g). On recovery, it was found that a short circuit in the battery prevented access to the data-logger. By supplying external power the data was recovered. On examination of the data, all channels were found to contain corrupted signals in the form of a square wave signal. Checks showed that the data-logger and accelerometers were still fully functional. Later x-rays of the battery revealed that several cells in the logger's battery circuit had collapsed (see Figure 6). This was probably due to a void in the potting compound around the cells. The other two battery circuits were fully functional.

CONCLUSIONS & RECOMMENDATIONS

Three 120mm instrumented proof shot rounds were built and fired from a smoothbore L30 gun system. Unfortunately, data on the in-bore motion of the projectile was not obtained due to three completely different failures modes of the instrumentation: water ingress into the battery/instrumentation compartment; false triggering of the data-logger and; cell collapse and failure within the battery.

However, all three data-loggers were fully functional after firing, together with most of the accelerometers. A small number of displacement transducers also survived. The overall design of the instrumented projectile appeared to have performed well. In addition all three rounds were launched with zero spin.

Some simple component level testing may have reduced the risk of instrumentation failure, particularly for the battery and displacement transducers, and some simplification of the design to reduce the complexity of the assembly procedure.

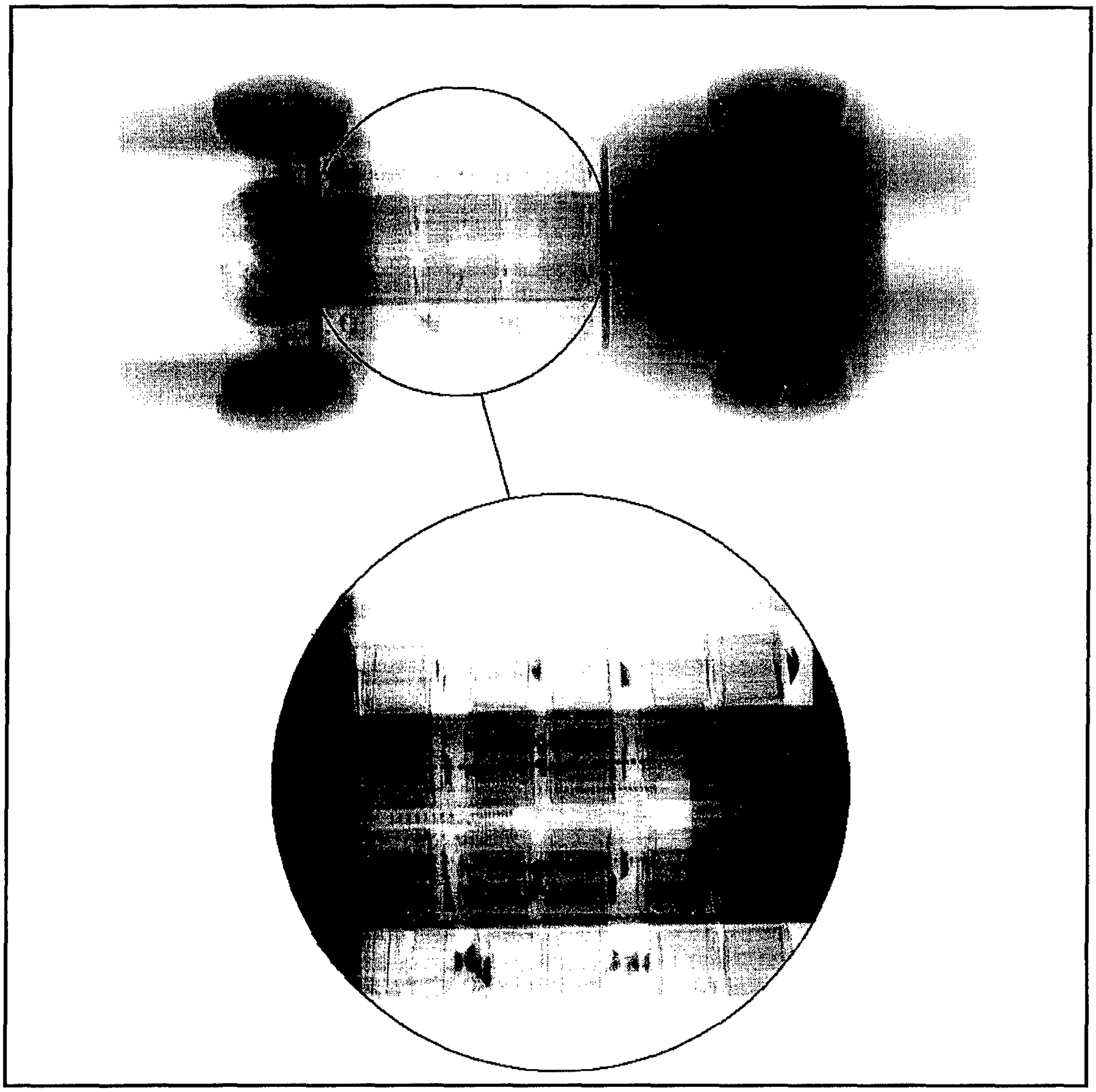

FIGURE 6. X-ray of fired projectile, highlighting battery failure.

A further trial was planned for this year but a funding cut has meant that this will not take place. Collaboration with other nations is the probably the best method now for validating the gun dynamics codes as other countries have similar programmes aimed at gaining experimental in-bore data [12,13].

These lessons are being incorporated into a series of instrumented firings planned for a 90mm electro-magnetic launcher.

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